The Origin of Fulton's Condition Factor—Setting the Record Straight

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In many instances in fisheries science, the origin of an idea seems obvious and there appears to be a complete trail of references which record the development of the idea. In reality, references to older literature are sometimes misquoted or misused and there may even be misinterpretations of the original article. As a case in point, the current attribution of the condition factor to Fulton is misleading, and obscures the contributions of early fishery scientists who first developed the methods for studying natural populations and methods for management. This essay is intended to reinstate the history of the development of this widely used tool, and to acknowledge the insight of the scientists who first linked weight and length measurements to condition. It is not the intention of this essay to discuss the merits or disadvantages of using length and weight measures as an indicator of the "condition," "well-being," "plumpness," etc., of a fish. Errors and incorrect attributions can become incorporated into subsequent publications and textbooks over time. Whether it is to correct a fundamental flaw or simply to set the record straight, these matters should be brought to the fore, as they become known.

Fulton's condition factor is widely used in fisheries and general fish biology studies. This factor is calculated from the relationship between the weight of a fish and its length, with the intention of describing the "condition" of that individual. The formula is of the form:

$$K = \frac{W}{L^3}$$

where K = Fulton's condition factor, W = the weight of the fish, and L is the length (usually total length). A scaling factor is usually applied to bring the factor close to 1. The history of the search for a relationship to describe fish condition, and the development of a mathematical tool for quantifying variations in fish populations, is an example of how rapidly the exchange of ideas can lead to progress in understanding fundamental principles about fish growth.

Fulton's condition factor is most often attributed with the citation Fulton (1911) *The Sovereignty of the Sea*. This citation is incorrect as it has no reference to "condition" in fish; rather, it is a history of how parts of maritime law came in to being, including the 3-mile zones around each country's shore line. If authors over the years had included the full title of the book (*The Sovereignty of the Sea: An Historical Account of the Claims of England to the Dominion of the British Seas and of the Evolution of the Territorial Waters, with Special Reference to the Rights of Fishing and the Naval Salute*) in their reference lists then the error would have been obvious (Valencia Hernández 2003). RDMN will admit to being one of these authors (Nash 1982), and this is a good example of how attribution errors occur. To be fair, Nash (1980) stated that the reference was cited in Ricker (1975) but the words "cited in" were lost during the conversion from a thesis chapter to a paper.

The other widely used reference for condition factor, Fulton 1904, is more relevant since here Fulton referred to the increase in weight conforming to the cube of the length (see argument in Valencia Hernández 2003). Fulton stated here (1904) that the cubic relationship is "broadly" true but it does not

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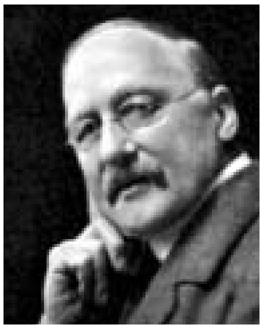
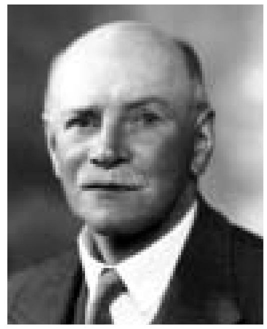


Thomas Wemyss Fulton

William Edwin Ricker

James "Jas" Johnstone



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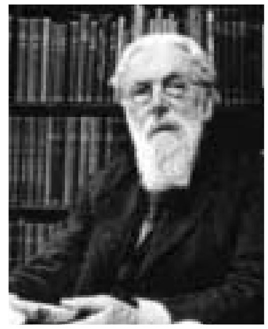

D'Arcy Wentworth Thompson

accurately reflect the true relationship between length and weight in fish.

To trace the origin of "Fulton's condition factor," citations to Fulton's condition factor and the use of condition factors in general in fish biology and fisheries were located using electronic bibliographic search tools. The purpose of this listing was to determine the source of the earliest mention of Fulton's condition factor—who first attributed K and its equation to Fulton. Given that neither Fulton 1904 nor Fulton 1911 specifically mention a condition factor, a further search was conducted directly through the writings and bibliographic citations of Fulton and his contemporaries. Original published documents from the period 1890–1925 were consulted, and the focus of the research was the use of the weight-length relationship as an index of condition in fish.

Fulton (1902, 1904) explored the relationship between length and weight of a number of different fish species. In the 1904 paper he studied fish growth through measures of length, volume, and weight but opted in the end to primarily use the weight of the fish, because it was easier (more "satisfactory"). He went on to say on page 142: "According to the well-known law, that the volume of similarly-shaped bodies of the same specific gravity vary directly as the cube of corresponding dimensions—a law which was brought prominently forward by Herbert Spencer in his *Principles of Biology*—a fish which has doubled its length should have increased its weight eight times." Spencer (1884:123) wrote that doubling of size results in an organism being eight times more heavy; however, he did not specifically refer to fish here. Fulton considered this "law" convenient for considering growth rates of fishes as all that is required is that one calculates the relationship between weight and one of the dimensions (linear) at a particular size and then calculates the ratio between that dimension and the weight at different sizes. Fulton (1904) made observations on a number of species at different times of the year, and noted that the ratio varied with species, location, and season. He suggested that the ratio varied due to reproductive state and the general "conditions of nutrition" brought about by seasonality or "other circumstances" in the environment. The reference to "conditions of …" could be construed as the first reference to a measure of "condition" of a fish but Fulton's meaning here is not clear.

Johnstone (1912) reviewed the development of the weight to length cubed formula in fish studies. He pointed out that Meek (1903) was the first to show a cubic relationship between length and weight. According to Johnstone (1912), the formula:

$$Weight(g) = K \cdot \left(\frac{(Length(cm))^3}{100}\right)$$

was first proposed by D'Arcy Thompson for fisheries investigations. During the previous decade other fishery biologists were busy studying the seasonality of fish growth, and exploring the relationships between increases in length and increases in weight. They probably were able to measure fish length with greater precision and accuracy than fish weight, especially at sea. An understanding of weight-length relationships would allow fish length to be converted to weight for the study of growth. However, the relationship between weight and length was not stable. For example, Johnstone (1905) reported on weights and lengths of Irish Sea European plaice (*Pleuronectes platessa*), and referred to Fulton's (1904) comment that the weight tended to increase more rapidly with length than the cubic law would suggest. This inconsistency probably provided the basis for the concept of condition.

Hecht (1916) also reported on the development of the condition factor idea. He stated that Hensen (1899), at the suggestion of Reibisch (1899), "divided the weight of a series of plaice by the cube of the length, in an attempt to get some weight-length relationship." He also pointed out that Meek (1903) found a relationship between weight and the cubic function of length and expanded on this in Meek (1905). Hecht (1916) suggested that Fulton (1904) was unaware of these activities and these results. Johnstone (1912) noted that Henking and Heincke (1907) adopted the formula given by D'Arcy Thompson. This exchange of ideas and applications was also recorded separately by Hecht (1916) when he reported that Heincke and co-workers adopted the cubic relationship, based on suggestions by D'Arcy Thompson, and used it for all their work on plaice.

Heincke (1908) also published the length-weight formula but additionally described the variability in the length-weight relationship over seasonal cycles and in relation to the spawning cycle. Significantly, he goes on to define K as a measure of the nutritional condition of a group of plaice caught at the same time and location. Heincke was probably the first to link K with fish condition, and stated that the better the condition of the fish, the higher the value of K. Thus, it was probably Heincke (1908) who first introduced K as an index of "condition" of fish into the literature.

Johnstone (1911) commented on the dependence of the value of a (normally referred to as K) on season and that this was the only "convenient index of condition" of plaice inhabiting a particular fishing ground (in this paper he wrote the word condition in quotation marks). However, Johnstone (1912) gave a fully developed description of fish condition. This was probably the first comprehensive definition of the "condition index." In this paper the equation

$$K = \frac{W}{L^3}$$

was called the Meek-D'Arcy Thompson formula.

Thompson (1917) utilized the formula

$$K = \frac{W}{L^3}$$

and illustrated the change in K of plaice with length (in this case K decreases after sexual maturity) and seasonal changes in K with spawning season. Thompson (1942) showed that the relationship between K and length varied seasonally due to spawning, e.g., prior to the spawning season the value of K

increased with length. Thompson (1942) called K the ponderal index and suggested that variations in K reflected not only the spawning state but also changes in appetite and general condition. Thompson (1942) attributed the ponderal index to Livi (1897, cited in Thompson 1942) where it was used in the form

$$\frac{\sqrt[3]{W}}{L}\ x100$$

Friedrich Heincke

After the early 1900s the use of the weight-length relationship as a tool for measuring fish condition became accepted and the formula

$$K = \frac{W}{L^3}$$

(where K is condition) became commonplace in the literature. Hile (1936) discussed the use of the cubic relationship for describing condition of fish and these ideas were developed further by Weatherley (1972). Carlander (1950) presented the cubic relationship as a standard method of assessing condition, and it was also discussed in Beverton and Holt (1957). None of these sources attributed the condition factor to any one source. In fact many authors still do not provide a reference for the equation.

However, the origin of the name "Fulton's condition factor" is undoubtedly Ricker (1975). This appears to be the first time that the idea of the "condition factor," and the equation

$$K = \frac{W}{L^3}$$

was attributed to Fulton. Whilst we do not advocate that the condition factor's name be changed and Fulton should retain credit for wrestling with the problem of using the assumption of the cubic "law," the present generation of fisheries scientists should be aware of how this "condition factor" came attributed to a specific fishery biologist, with a citation referring to maritime law. The correct citation for Fulton's condition factor should be Ricker (1975).

In summary, it was F. Heincke in the Helgoland Laboratory who first utilised K (what is now known as Fulton's condition factor) as a measure of the condition of fish (Heincke 1908). J. Johnstone of the Fisheries Laboratory of the Liverpool Biological Society, Liverpool, further clarified the use of K as an index of condition in fish. The literature is often confusing since there are many arguments surrounding the use of condition factors and what they mean. Many of the authors mentioned above (including Johnstone and others in the early 1900s) pointed out the problems with using K as a simple measure of condition. This essay provides the correct historical background as a platform for those arguments concerning appropriate measures of condition.

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